Spin structure and longitudinal polarization of hyperon in e^+e^- annihilation at high energies

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Abstract

Longitudinal polarizations of different kinds of hyperons produced in e^+e^- annihilation at LEP I and LEP II energies in different event samples are calculated using two different pictures for the spin structure of hyperon: that drawn from polarized deep inelastic lepton-nucleon scattering data or that using SU(6) symmetric wave functions. The result shows that measurements of such polarizations should provide useful information to the question of which picture is more suitable in describing the spin effects in the fragmentation processes.

1. Introduction

Spin effects in high energy fragmentation processes have attracted much attention[1] recently. Study of such effects provide useful information for the spin structure of hadron and spin dependence of high energy reactions. There exist now two distinctively different pictures for the spin contents of the baryons: the static quark model picture using SU(6) symmetric wave function [hereafter referred as SU(6) picture], and the picture drawn from the data for polarized deep inelastic lepton-nucleon scattering (DIS)[9] and SU(3) flavor symmetry in hyperon decay [hereafter referred as DIS picture]. It is natural to ask which picture is suitable to describe the relationship between the polarization of the fragmenting quark and that of the produced hadron. It has been pointed out in [6] that measurements of Λ longitudinal polarization in e^+e^- annihilation at high energies can provide useful information to answer this question. Calculations based on these two different pictures have been made in [4] and [6]. A comparison of the obtained results with the ALEPH data[10] obtained at LEP, which was available at that time, was made. The result shows that the SU(6) picture seems to agree better with the data[10]. This is rather surprising since the energy is very high at LEP and the initial quarks and anti-quarks produced at the annihilation vertices of the initial e^+e^- are certainly current quarks and current anti-quarks rather than the constituent quarks used in describing the static properties of hadrons using SU(6) symmetric wave functions. Other models[7,8] are also proposed which can give a description of the available data[10]. The available data[10] are certainly still far from accurate and abundant enough to make a conclusive judgment of these different models. It is therefore important and urgent to make further checks of this conclusion by performing complementary measurements.

In this paper, we formulate the calculation method of longitudinal polarization of different hyperons in e^+e^- annihilation at high energies proposed in [4] and [6] in a systematic way so that they can be generalized to other hyperons and/or other reactions. We describe in detail the inputs and/or assumptions which have been used in the calculations. We then present the calculated results for different hyperons based on these two pictures. We present

the results for the whole events as well as those for different particularly chosen event samples. We show that corresponding measurements can be used as complementary method to check the above mentioned conclusion. In particular, we discuss also how to distinguish such models from the kind of models proposed in [7,8]. In section 2, we outline the calculation method and present the results for Λ polarization. In section 3, we present our results for other hyperons.

2. The calculation method and the results for Λ in different event samples

We recall that[11], according to the standard model of electroweak interactions, quarks and anti-quarks produced at the annihilation vertices of e^+e^- are longitudinally polarized. Such longitudinal quark polarization can be transferred to the produced hadron which contains the initial quark thus lead to longitudinal polarization of hadron in the inclusive process $e^+e^- \rightarrow h + X$. Measuring the polarizations of the produced hadrons, we can study the relation between the spin of the fragmenting quark and that of the produced hadron which contains that quark. In this aspect, the $J^P = \frac{1}{2}^+$ hyperons are most suitable candidates among all the hadrons. This is because these hyperons decay weakly so that their polarizations can easily be obtained from the angular distributions of their decay products. We now outline the calculation method of the longitudinal polarization P_{H_i} of different hyperon H_i in the inclusive process $e^+e^- \rightarrow H_i + X$.

A. The calculation method for different hyperons

Since the longitudinal polarization P_{H_i} of the hyperon H_i in the inclusive process $e^+e^- \rightarrow H_i + X$ originates from the longitudinal polarization P_f of the initial quark q_f^0 (where the subscript f denotes its flavor) produced at the annihilation vertex of the initial state e^+e^-, we should consider the H_i's which have the following different origins separately.

(a) Hyperons which are directly produced and contain the initial quarks q_f^0's originated

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from the annihilations of the initial e^+ and e^-;

(b) Hyperons which are decay products of other heavier hyperons which were polarized before their decay;

(c) Hyperons which are directly produced but do not contain any initial quark q_f^0 from e^+e^- annihilation;

(d) Hyperons which are decay products of other heavier hyperons which were unpolarized before their decay.

It is clear that hyperons in groups (a) and (b) can be polarized. Those in group (a) are polarized[4,6] since the polarization of the initial quark q_f^0 can be transferred to such hyperon H_i's in the fragmentation process. We denote the probability for this polarization transfer by $t_{H_i,f}^F$ and call it polarization transfer factor from quark q_f to hyperon H_i, where the superscript F stands for fragmentation. Hyperons in group (b) can be polarized since such hyperons can inherit part of the polarization of the parent hyperons in the decay process. We denote the probability for this polarization transfer by t_{H_i,H_j}^D and call it polarization transfer factor from hyperon H_j to hyperon H_i, where the superscript D stands for decay. In contrast, hyperons in groups (c) and (d) are unpolarized. Hence, we obtain that the polarization of the final hyperon is,

$$P_{H_i} = \frac{\sum\limits_f t_{H_i,f}^F P_f \langle n_{H_i,f}^a \rangle + \sum\limits_j t_{H_i,H_j}^D P_{H_j} \langle n_{H_i,H_j}^b \rangle}{\langle n_{H_i}^a \rangle + \langle n_{H_i}^b \rangle + \langle n_{H_i}^c \rangle + \langle n_{H_i}^d \rangle}. \tag{1}$$

Here P_f is the polarization of the initial quark q_f^0; $\langle n_{H_i,f}^a \rangle$ is the average number of the hyperons which are directly produced and contain the initial quark of flavor f; P_{H_j} is the polarization of the hyperon H_j before its decay; $\langle n_{H_i,H_j}^b \rangle$ is average numbers of H_i hyperons coming from the decay of H_j hyperons which are polarized; $\langle n_{H_i}^a \rangle (\equiv \sum\limits_f \langle n_{H_i,f}^a \rangle)$, $\langle n_{H_i}^b \rangle (\equiv \sum\limits_j \langle n_{H_i,H_j}^b \rangle)$, $\langle n_{H_i}^c \rangle$ and $\langle n_{H_i}^d \rangle$ are average numbers of hyperons in group (a), (b), (c) and (d) respectively. These different factors can be calculated in the following way.

Longitudinal polarization of the initial quark q_f^0 is determined by the standard model for electroweak interactions. The polarization comes from the weak interactions and the results for $e^+e^- \to \gamma^*/Z \to q_f^0 \bar{q}_f^0$ can be found e.g. in [11], i.e.,

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$$P_f = -\frac{A_f(1 + \cos^2\theta) + B_f \cos\theta}{C_f(1 + \cos^2\theta) + D_f \cos\theta}, \tag{2}$$

where θ is the angle between the outgoing quark and the incoming electron, the subscript f denotes the flavor of the quark, and

$$A_f = 2a_f b_f(a^2 + b^2) - 2(1 - \frac{m_Z^2}{s})Q_f ab_f, \tag{3}$$

$$B_f = 4ab(a_f^2 + b_f^2) - 2(1 - \frac{m_Z^2}{s})Q_f a_f b, \tag{4}$$

$$C_f = \frac{(s - m_Z^2)^2 + m_Z^2\Gamma_Z^2}{s^2}Q_f^2 + (a^2 + b^2)(a_f^2 + b_f^2) - 2(1 - \frac{m_Z^2}{s})Q_f aa_f, \tag{5}$$

$$D_f = 8aba_f b_f - 4(1 - \frac{m_Z^2}{s})Q_f bb_f, \tag{6}$$

where m_Z and Γ_Z are the mass and decay width of Z;

$$a = \frac{-1 + 4\sin^2\theta_W}{2\sin 2\theta_W}, \tag{7}$$

$$b = -\frac{1}{2\sin 2\theta_W}, \tag{8}$$

$$a_f = \begin{cases} \frac{1 - 8\sin^2\theta_W/3}{2\sin 2\theta_W}, & \text{for } f = u, c, t, \\ \frac{-1 + 4\sin^2\theta_W/3}{2\sin 2\theta_W}, & \text{for } f = d, s, b, \end{cases} \tag{9}$$

$$b_f = \begin{cases} \frac{1}{2\sin 2\theta_W}, & \text{for } f = u, c, t, \\ -\frac{1}{2\sin 2\theta_W}, & \text{for } f = d, s, b, \end{cases} \tag{10}$$

are the vector and axial vector coupling constants of electron and quark to Z boson, and θ_W is the Weinberg angle. To see the size and the θ-dependence of P_f, we show in Fig.1 the numerical results of $-P_f$ as a function of $\cos\theta$ at LEP I energy. We see clearly that all the quarks produced at the e^+e^- annihilation vertices are longitudinally with significantly high polarizations. We see also that the magnitude of the polarization of the down-type quarks

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$(d, s$ and $b)$ is large and varies little with the angle θ, while that of the up-type quarks $(u$ and $c)$ is a little bit smaller and has a relatively larger variation in the whole range of $\cos\theta$. The latter increases with $\cos\theta$ from 0.58 at $\cos\theta = -1$ to 0.74 at $\cos\theta = 1$. Averaging over θ, we obtain,

$$\langle P_f \rangle = \frac{\int P_f \sigma^0 d\cos\theta}{\int \sigma^0 d\cos\theta} = -\frac{A_f}{C_f}, \tag{11}$$

where $\sigma^0 = C_f(1+\cos^2\theta) + D_f \cos\theta$ is the angular variation of the unpolarized cross section. In Fig.2, we show $-\langle P_f \rangle$ as a function of the total e^+e^- center-of-mass energy $\sqrt{s}$. We see that, at the LEP I energy, i.e. $\sqrt{s} = 91 GeV$, the polarizations of quarks have the maximum negative value, i.e., $\langle P_f \rangle = -0.67$ for $f = u, c$, and $\langle P_f \rangle = -0.94$ for $f = d, s$, and b. From the LEP I energy to the LEP II energy, the polarizations decrease a bit but it is still very large at the LEP II energy $(\sqrt{s} = 200 GeV)$, where we have $\langle P_f \rangle = -0.26$ for $f = u, c$, and $\langle P_f \rangle = -0.8$ for $f = d, s$, and b.

At LEP II energy, the W^+W^- events, i.e. $e^+e^- \rightarrow W^+W^- \rightarrow q_{f1}\bar{q}_{f2}q_{f3}\bar{q}_{f4}$, are significant. It takes about 10% of the whole events. The polarizations for the initial quarks in such events are different from those in $e^+e^- \rightarrow \gamma^*/Z^0 \rightarrow q_f\bar{q}_f$, and should be considered separately in the calculations. According to the standard model for electroweak interactions, the polarization of initial quark and that of initial anti-quark created in W^+ or W^- decay vertex are equal to -1.0 and 1.0, respectively. There exists also another type of events, i.e. $e^+e^- \rightarrow Z^0Z^0 \rightarrow q_{f1}\bar{q}_{f1}q_{f2}\bar{q}_{f2}$, which contribute at LEP II energy. But this contribution is very small (less than 1%). We will not consider such events in the following calculations.

The fragmentation polarization transfer factor $t^F_{H_i,f}$ from the initial quark q_f to hyperon H_i is equal to the fraction of spin carried by the f-flavor-quark divided by the average number of quark of flavor f in the hyperon H_i[4,6]. This fractional contribution to the hyperon spin from f-flavor-quark is different in the above-mentioned SU(6) or the DIS picture. The results in the SU(6) picture can easily be obtained from the wave functions. In the DIS picture, the fractional contribution of quarks of different flavors to the spin of a baryon in the $J^P = \frac{1}{2}^+$ octet is extracted from $\Gamma^p_1 \equiv \int_0^1 g^p_1(x)dx$ obtained in deep-inelastic lepton-proton scattering

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experiments[9] and the constants F and D obtained from hyperon decay experiments. The way of doing this extraction is now in fact quite standard (see, for example, the Appendix in [6]). The results for Λ, Σ^0 and Ξ hyperons have been obtained in [5] and [6]. Using exactly the same way, we obtain also the results for $\Sigma^\pm$. For completeness, we list the results for all the $J^P = \frac{1}{2}^+$ hyperons in Table 1.

In the calculations, we take also the contributions from the decay of $J^P = \frac{3}{2}^+$, i.e. the decuplet hyperons into account. The polarizations of such hyperons in the SU(6) picture can easily be calculated using the SU(6) symmetric wave functions. But, it is presently impossible to calculate them in the DIS picture since no DIS data is available for any one of the decuplet baryons. Therefore, in the calculation we take them into account in the same way as those in the SU(6) picture.

The decay polarization transfer factor $t^D_{H_i,H_j}$ is determined by the decay process and is independent of the process in which H_j is produced. The results for different decay processes are different and will be given for each individual hyperon in the following sections of this paper.

After we obtain the results for P_f, $t^F_{H_i,f}$ and $t^D_{H_i,H_j}$, we can calculate P_{H_i} if we know the average numbers $\langle n^a_{H_i,f}\rangle$, $\langle n^b_{H_i,H_j}\rangle$, $\langle n^c_{H_i}\rangle$, and $\langle n^d_{H_i}\rangle$ for hyperons H_i from the different origins. These average numbers are determined by the hadronization mechanism and should be independent of the polarization of the initial quarks. Hence, we can calculate them using the a hadronization model which give a good description of the unpolarized data for multiparticle production in high energy reactions. Presently, such calculations can only be carried out using a Monte-Carlo event generator. We use the Lund string fragmentation model[12] implemented by JETSET[13] in the following.

B. Λ polarization in the average events

Among all the $J^P = \frac{1}{2}^+$ hyperons, Λ is most copiously produced. Furthermore, the spin structure of Λ in the $SU(6)$ picture is very special, which makes it play a very special role in

distinguishing the $SU(6)$ and the DIS pictures. In the $SU(6)$ picture, spin of Λ is completely carried by the s valence quark, while the u and d quarks have no contribution. Since the initial s quark produced in the annihilation of the initial e^+e^- takes the maximum negative polarization, $|P_\Lambda|$ obtained using the SU(6) picture is the maximum among all the different models. In contrast, in the DIS picture, the s quark carries only about 60% of the Λ spin, while the u or d quark each carries about -20% (see Table 1). The resulting $|P_\Lambda|$ should be substantially smaller than that obtained in the $SU(6)$ picture. Comparing the maximum with experimental results provide us a good test of the validity of the picture.

Λ is also the lightest hyperon, so the final Λ's produced in high energy reactions contain contributions from the decays of many different heavier hyperons. There are three octet, i.e. Σ^0, Ξ^0 and Ξ^-, and five decuplet, i.e., $\Sigma(1385)^{\pm,0}$ and $\Xi(1530)^{-,0}$, hyperons that can decay to Λ. The polarization transfer in $\Sigma^0 \to \Lambda\gamma$ has been studied in [14], the result for the polarization transfer factor t^D_{Λ,Σ^0} is $-1/3$. $\Xi \to \Lambda\pi$ is a parity non-conserving decay and is dominated by S-wave. The polarization transfer $t^D_{\Lambda,\Xi}$ for this process is equal to $(1 + 2\gamma)/3$, where $\gamma = 0.87$ can be found in Review of Particle Properties [15]. The decay process from the decuplet hyperon to octet hyperon and a pseudo-scalar meson π such as $\Sigma(1385) \to \Lambda\pi$ or $\Xi(1530) \to \Xi\pi$ is dominated by the P wave[4], and the octet hyperon will get the same polarization as that of the initial decuplet hyperon, i.e., $t^D = 1$. For explicity, we list all these results for t^D_{Λ,H_j} in table.2. There are also some contributions from the decays of open charm or open beauty baryons. The polarization transfer factors in these decay processes are unfortunately unknown yet. This is a theoretical uncertainty in the calculations. However, according to the materials in Review of Particle Properties[15], we do know that each of these open charm or open beauty baryons can decay to Λ through many different channels. The contributions to Λ polarization in these different channels may be quite different. We expect that the net contribution from all these channels cannot be large. We will just neglect it in our calculations.

Using JETSET and PYTHIA, we obtain the average numbers $\langle n^a_{\Lambda,f} \rangle$, $\langle n^b_{\Lambda,H_j} \rangle$, $\langle n^c_\Lambda \rangle$, and $\langle n^d_\Lambda \rangle$ at $\sqrt{s} = 91$ GeV and those at $\sqrt{s} = 200$ GeV, respectively. We show them in Fig.3 and

Fig.4. The results at $\sqrt{s} = 91$ GeV are of course the same as those in [4] and [6]. From these figures, we see clearly that contribution to Λ from the events originating from the initial s quarks play the most important role, in particular for large z. For example, for $z > 0.4$, it gives about 70% of the whole Λ's, while those from the events initiated by u or d take only 10% respectively.

Using the results for the P_f's, the $t^D_{H_i,f}$'s, and the $t^D_{H_i,H_j}$'s mentioned above, we obtain the longitudinal polarization of Λ as shown in Fig.5. A comparison of those results at LEP I with the ALEPH data[10] and the OPAL data[16] shows that the data[10,16] of both groups agree better with the calculated results based on the $SU(6)$ picture. But, these available data[10,16] are still far from accurate and enormous enough to make a decisive conclusion. Further complementary measurements are needed.

At the LEP II energy, W^+W^- events take about 10% of the whole events. We expect that such events give a even more significant contribution to Λ polarization, since the polarization of the initial quark at W^+ or W^- decay vertex is 100%, which is larger than those from the $e^+e^- \rightarrow \gamma^*/Z^0 \rightarrow q^0_f \bar{q}^0_f$. Since there are two initial quarks and two initial anti-quarks in W^+W^- events, the energy of each of them should be much smaller than those in the $e^+e^- \rightarrow \gamma^*/Z^0 \rightarrow q^0_f \bar{q}^0_f$ events. Hence, such events should contribute mainly in relatively smaller z regions. Adding all the different together, we obtain[18] P_Λ at LEP II energy shown in Fig.5. We see that, compared with those obtained at the LEP I energy, $|P_\Lambda|$ at LEP II energy is a little larger at small z region, and is a little smaller at large z region. This is consistent with the above-mentioned qualitative expectations and can be checked experimentally.

C. Λ polarization in different subsamples of events

In the two models we discussed above, Λ polarization comes solely from the hyperons which contain the initial quark created at the e^+e^- annihilation vertex. The contributions are very much different for the hyperons which contain the initial s from those which contain

the initial u or d quarks. There is also a big differences between the contribution from the hyperons which contain the initial quarks and that from those which do not. It is thus clear that we can get a further check of the two pictures if we study the Λ polarization in events which originate from the initial u or d quark or those which originate from the initial s quark separately. We should also get a very sensitive check to different pictures if we study only those Λ's which contain the initial quarks.

In this connection, it should also be mentioned that there exist another different type of models[7,8] for spin transfer in fragmentation processes. In contrast to that described in subsection 2 A, in these models, no distinction is made between the hyperons which contain the initial quarks or those which do not contain the initial quarks. Some of them[8] even do not distinct those which are directly produced or those which come from heavier hyperon decays. In other words, in these models, there is no distinction between hyperons from the groups (a), (b), (c) and (d). It is simply assumed that a "reciprocity relation" is valid between the fragmentation function for the final hyperons and the corresponding quark distribution functions in the hyperons. They are taken as proportional to each other, with a proportional constant which is common for quarks of different flavors. The hyperon polarization can easily be calculated in such models if the spin-dependent quark distribution functions are known. The obtained results depend obviously very much on the spin-dependent quark distributions, which are used as theoretical input. Since the spin dependent quark distributions in hyperons are still poorly known yet, the obtained results can be very much different from each other if different sets of quark distributions are used. But, since the (polarized) fragmentation function from a given quark q_f^0 to a given hyperon H_i depends only on the fractional momentum z of the quark carried by the produced hyperon, the obtained polarization at a given z should be completely the same if we study only those hyperons which contain the initial quarks or all of them in events originating from a given type of initial quark.

It is unfortunately impossible to make a complete separation of hyperons in these different groups in experiments. However, it should be possible to separate the events into

different subsamples, in each of which the hyperons from one group dominate. Measuring Λ polarization in such subsamples of events should give further complementary checks of the different models mentioned above. Using the Monte-Carlo event generator JETSET[13], we can study the various possibilities in this direction. We note that, if a Λ originates from the initial s quark, the leading particle in the opposite direction should contain the $\bar{s}$ produced in the e^+e^- annihilation vertex. Hence, we choose an event sample according to the following criteria:

(i) Λ is the leading in one direction;

(ii) the leading particle in the opposite direction is K^+.

We expect that such Λ's should mainly have the origin (a) mentioned in the subsection 2 A. In Fig.6, we show the results obtained from JETSET for the average numbers of Λ's of different origins. We see that such leading Λ's indeed mainly originate from the initial s quark. The contribution from the initial u or d quark is indeed substantially small. It takes only about 3% of such Λ's. In particular, in $z > 0.5$ region there is almost no contribution from the initial u or d quark at all.

Using Eq.(1), we calculated P_Λ for the events under the conditions (i) and (ii) using the SU(6) and the DIS pictures. The comparison of the obtained results with those obtained in the average events are shown in Fig.7. We see that there is indeed a significant difference between the results obtained for such particularly chosen events and those for the average events in particular in the region of $z > 0.3$. Checking such differences by measuring P_Λ for such events can be helpful in distinguishing the validity of different pictures for the spin transfer in fragmentation processes.

3. Longitudinal polarization of other $J^P = \frac{1}{2}^+$ hyperons

The production rates for other octet hyperons are smaller than that for Λ so the statistic errors should be larger for the polarizations of these hyperons. On the other hand, decay contributions from heavier hyperons to these hyperons are also much less significant than

that in case of Λ. Hence, the contaminations from the decay processes are much smaller. These conclusions can easily be checked using a Monte-Carlo event generator for e^+e^- annihilation into hadrons. In Fig.8, we show the results obtained from JETSET for these hyperons compared with those for Λ. We see that, the production rate for Σ^+ or Ξ^0 is less than 20% of that for Λ. On the other hand, we see also that the contribution from heavier hyperon decays is also much smaller. For example, for Σ^+'s, the decay contribution takes only about 7% of the total rate. The situations for Σ^-, Ξ^0, and Ξ^- are similar to that for Σ^+. Most of them are directly produced. Hence, the theoretical uncertainties in the calculations for these hyperons are much smaller. The study of polarizations of these hyperons should provide us with good complementary tests of different pictures. In this section, we calculate the longitudinal polarizations of these hyperons, i.e., Σ^+, Σ^-, Ξ^0 and Ξ^-, in e^+e^- annihilation at LEP I and LEP II energies.

The calculations are quite similar to those for Λ production. The general procedure is the same and has been outlined in last section. The polarization transfer factor $t^F_{H_i,f}$ are given in table 1. The situation for decay contributions is quite simple: There are only contribution from the corresponding decuplet hyperon decays. More precisely, Σ contains only decay contribution from $\Sigma(1385)$ and Ξ has the decay contribution from $\Xi(1530)$. Both decay processes are strong decays and are dominated by the P-wave. The polarization transfer is the same as that in $\Sigma(1385) \to \Lambda\pi$, i.e. $t^D_{\Sigma,\Sigma(1385)} = t^D_{\Xi,\Xi(1530)} = 1$.

Before we present the numerical results of the calculations, we would like to note the following qualitative expectations.

First, although the spin structure of Σ^+ and that of Σ^- or that of Ξ^0 and that of Ξ^- are symmetric under the exchange of u and d (c.f. Table 1), their polarizations should be quite different from each other. This is because the polarization of the initial u and that of the initial d produced at the e^+e^- annihilation vertices are quite different. This can be seen clearly in Fig.1, where we see that the magnitude of the polarization of u quark is smaller than that of d quark.

Second, from Table 1, we see that the contributions from the two different flavors in these

hyperons ($\Sigma^{+,-}$, $\Xi^{0,-}$) are quite different: they have different signs and different magnitudes, and the differences are also different in the SU(6) or the DIS picture. This implies that their contributions to hyperon polarizations are also quite different. They should have different signs and different magnitudes. These differences make the situation very interesting. We should have different expectations for different hyperons. Even the signs of polarizations of some hyperons in the two different pictures can be different from each other.

Using JETSET and PYTHIA, we calculated the different contributions to Σ^+, Σ^-, Ξ^0 and Ξ^- from all the different sources discussed above at LEP I and LEP II, respectively. The results at LEP I energy are shown in Fig.9. Those at LEP II energy are similar and are not shown. From this Fig.9, we see that the Σ^+'s mainly come from the initial s and the initial u-quark, and that the Σ^-'s come mainly from the initial s and the initial d-quark, and that these two contributions are comparable with each other in particular for Σ^-'s. In contrast, the source for $\Xi^{0,-}$ is very pure: They come predominately from the initial s-quarks. All the others are negligible.

Using Eq.(1) and the results shown in Fig.9, we calculated the hyperon polarizations, P_{Σ^+}, P_{Σ^-}, P_{Ξ^0} and P_{Ξ^-}. The obtained results are shown in Fig.10. From these results, we see clearly that the polarizations are different for these different hyperons, and that there are considerably large differences between the results using the $SU(6)$ picture and those using the DIS picture. In particular, we see that P_{Σ^+} in the $SU(6)$ picture has opposite sign to that in the DIS picture. But their magnitudes are relatively small. The magnitude of P_{Ξ^0} and that of P_{Ξ^-} are considerably larger, in particular in the large z region. This is because the contribution to Ξ^0 or Ξ^- is very clear. They come mainly from the initial s-quark. There is thus little theoretical uncertainty in calculating P_Ξ. Hence, although the statistics may be much worse than Λ, there are still good reasons to study P_Ξ in $e^+e^- \to \Xi + X$ at LEP energies.

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18. It should be mentioned that, at the LEP II energy, the magnitude of the polarization of the initial quark produced in $e^+e^- \rightarrow \gamma^*/Z^0 \rightarrow q_f\bar{q}_f$ can be influenced by the initial

state radiation. Such initial state radiation reduces the effective energy of the e^+e^- at the annihilation vertex thus the polarization of P_f in such events should take the value at the corresponding lower energy. But, since P_f varies only slowly with the energy, this effect cannot be large. We neglect it in the calculations.

Table 1. Fractional contributions ΔU, ΔD and ΔS of the light flavors to the spin of baryons in the $J^P = \frac{1}{2}^+$ octet calculated using the $SU(6)$ picture and those obtained using the data for deep inelastic lepton-nucleon scattering and those for hyperon decay under the assumption that SU(3) flavor symmetry is valid. The first column shows the obtained expressions in terms of Σ, F and D. The $SU(6)$ picture results are obtained by inserting $\Sigma = 1, F = 2/3$ and $D = 1$ into these expressions and those in the third column are obtained by inserting $\Sigma = 0.28$, obtained from deep inelastic lepton-nucleon scattering experiments [9], and $F + D = g_A/g_V = 1.2573, F/D = 0.575$ obtained [15,17] from the hyperon decay experiments.

	Λ			Σ^0		
		$SU(6)$	DIS		$SU(6)$	DIS
ΔU	$\frac{1}{3}(\Sigma - D)$	0	-0.17	$\frac{1}{3}(\Sigma + D)$	2/3	0.36
ΔD	$\frac{1}{3}(\Sigma - D)$	0	-0.17	$\frac{1}{3}(\Sigma + D)$	2/3	0.36
ΔS	$\frac{1}{3}(\Sigma + 2D)$	1	0.62	$\frac{1}{3}(\Sigma - 2D)$	-1/3	-0.44
	Σ^+			Σ^-		
		$SU(6)$	DIS		$SU(6)$	DIS
ΔU	$\frac{1}{3}(\Sigma + D) + F$	4/3	0.82	$\frac{1}{3}(\Sigma + D) - F$	0	-0.01
ΔD	$\frac{1}{3}(\Sigma + D) - F$	0	-0.10	$\frac{1}{3}(\Sigma + D) + F$	4/3	0.82
ΔS	$\frac{1}{3}(\Sigma - 2D)$	-1/3	-0.44	$\frac{1}{3}(\Sigma - 2D)$	-1/3	-0.44
	Ξ^0			Ξ^-		
		$SU(6)$	DIS		$SU(6)$	DIS
ΔU	$\frac{1}{3}(\Sigma - 2D)$	-1/3	-0.44	$\frac{1}{3}(\Sigma + D) - F$	0	-0.10
ΔD	$\frac{1}{3}(\Sigma + D) - F$	0	-0.10	$\frac{1}{3}(\Sigma - 2D)$	-1/3	-0.44
ΔS	$\frac{1}{3}(\Sigma + D) + F$	4/3	0.82	$\frac{1}{3}(\Sigma + D) + F$	4/3	0.82

Table 2. The polarization transfer factors $t^D_{H_i,H_j}$ from hyperon H_j to hyperon H_i in the decay processes.

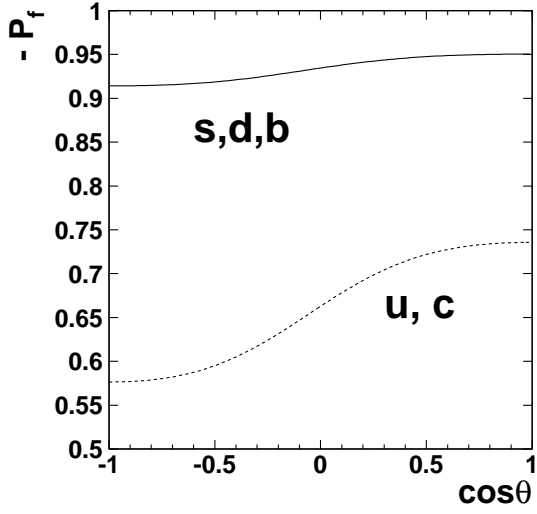|	$t^D_{H_i,H_j}$
$\Sigma^0 \to \Lambda\gamma$	-1/3
$\Xi \to \Lambda\pi$	$(1+2\gamma)/3$
$\Sigma(1385) \to \Lambda\pi$	1
$\Xi(1530) \to \Xi\pi$	1
$\Sigma(1385) \to \Sigma\pi$	1

Fig. 1.   Longitudinal polarization $-P_f$ of quark q_f produced at the e^+e^- annihilation vertex as a function of $\cos\theta$ at $\sqrt{s} = 91 GeV$.
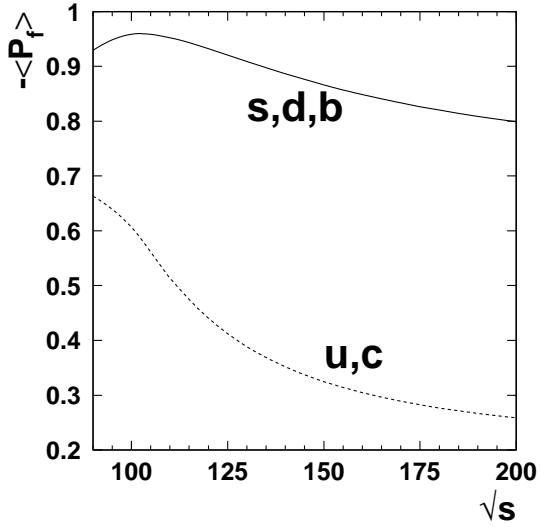

Fig. 2.   Average values $-\langle P_f \rangle$ of the longitudinal polarization of quark q_f produced at the e^+e^- annihilation vertex as a function of the total c.m. energy $\sqrt{s}$ of the e^+e^- system.
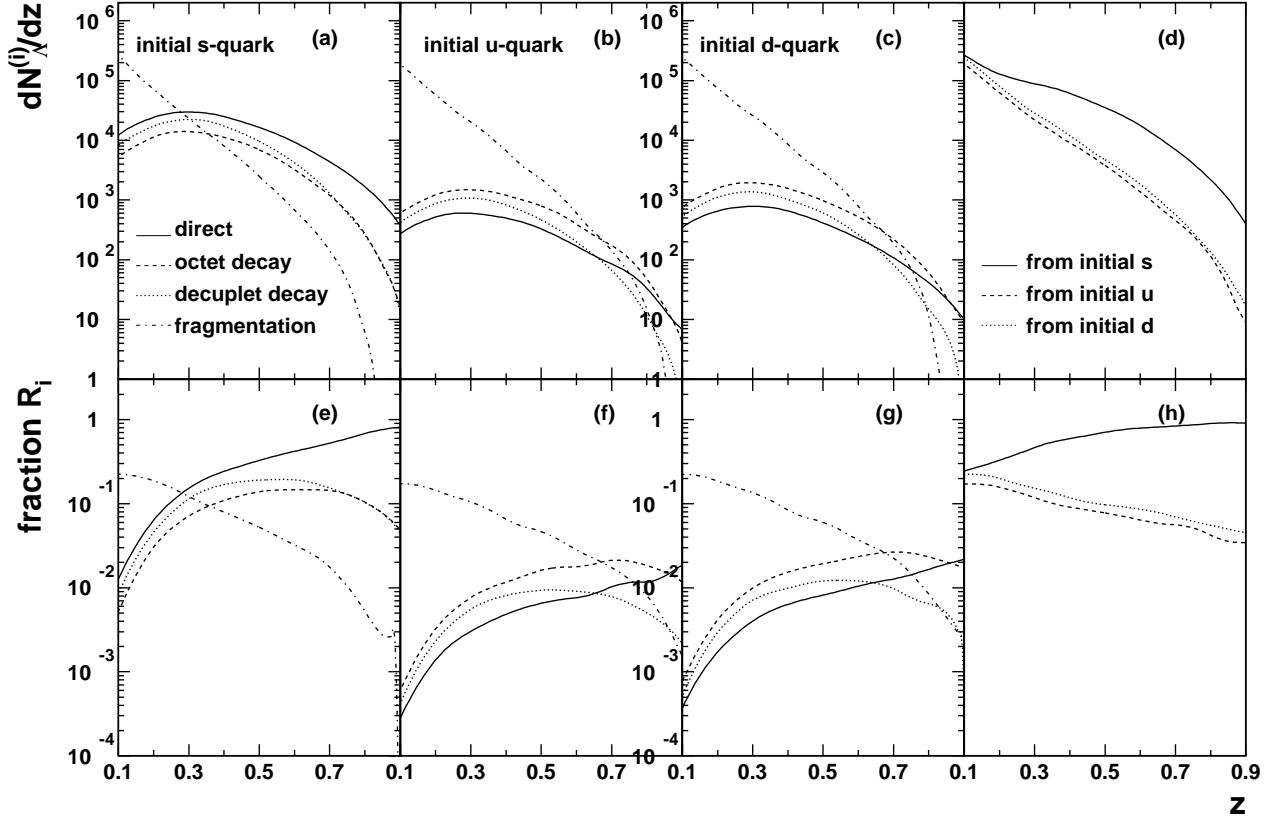
Fig. 3. Comparison of different contributions to Λ in events originating from the initial s, u, or d quark as functions of $z \equiv 2p/\sqrt{s}$ at LEP I energy. In Figs.(a), (b) and (c), we see the four types of contributions in initial s, u or d events respectively. Here, "directly" denotes those which are directly produced and contain the initial quark; "octet decay" and "decuplet decay" denote respectively those from the decay of the octet and the decuplet hyperons which contain the initial quark; "fragmentation" denotes those directly produced but do not contain the initial q^0 plus those from unpolarized hyperon decay. In Figs. (e), (f) and (g), we see the fractions R_i which are the ratios of the corresponding contributions to the sums of all these different contributions. In Figs. (d) and (h), we see the total contributions from events with initial s, u or d and the corresponding fractions respectively.

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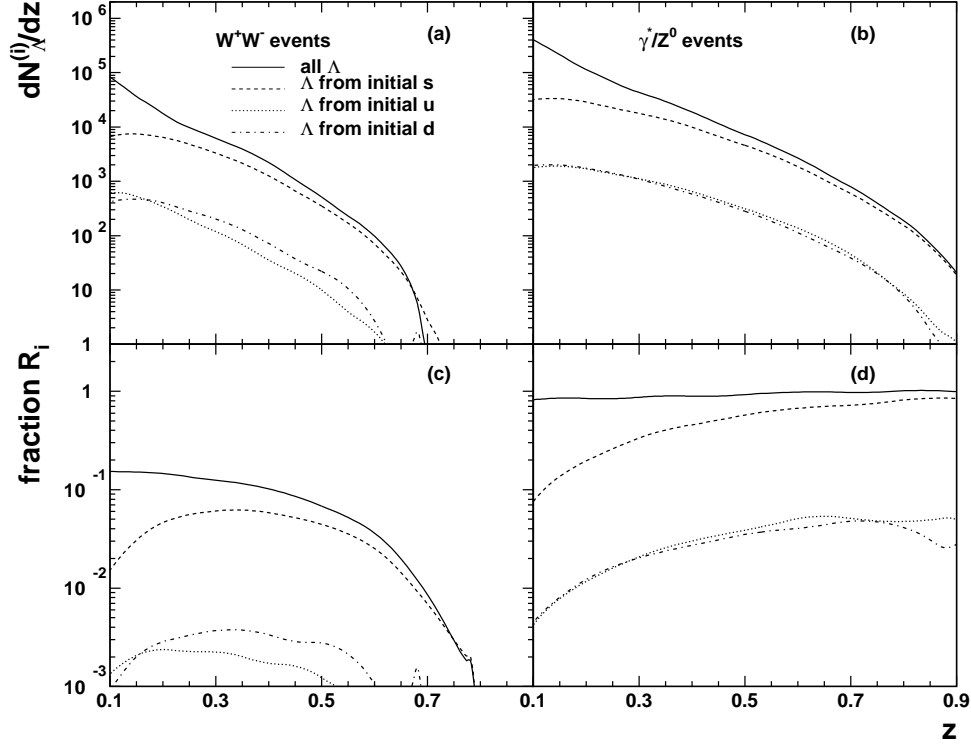
Fig. 4. Comparison of the different contributions to Λ in $e^+e^- \to W^+W^- \to \Lambda + X$ events and those in $e^+e^- \to \gamma^*/Z^0 \to \Lambda + X$ events at LEP II energy. In Figs.(a) and (d), we see the contributions from initial s, u or d quark in these two classes of events. Here, the contributions include only those contributing to Λ polarization, i.e., they are the sums of those which are directly produced and contain the initial quarks with those from polarized heavier hyperon decays. Figs.(c) and (d) represent the corresponding ratios to all Λ in $e^+e^- \to \Lambda + X$.
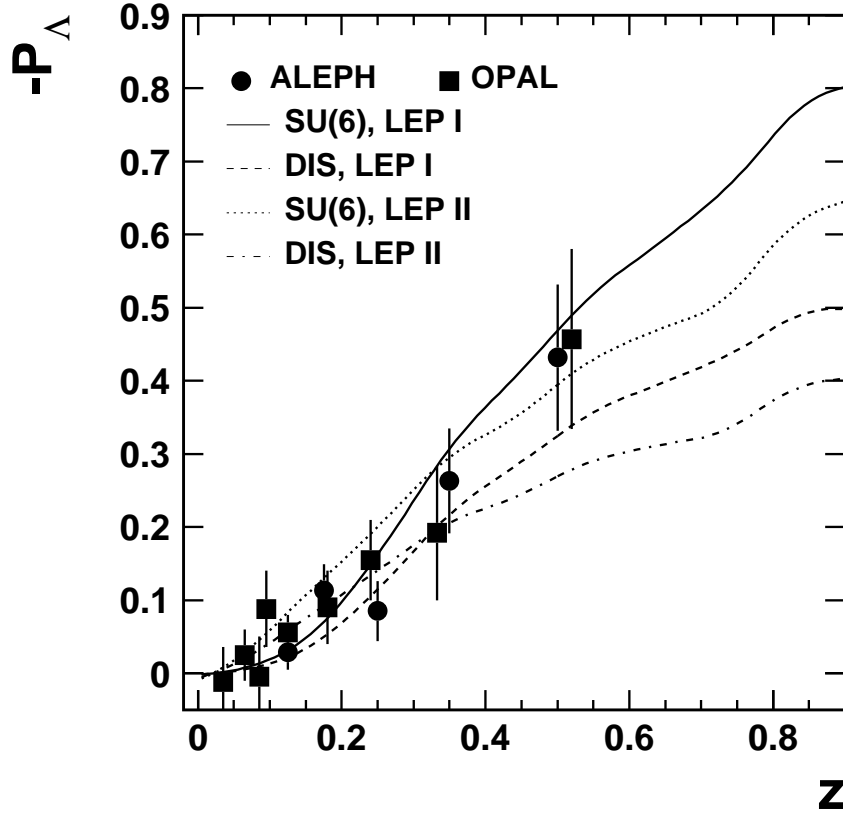
Fig. 5. Longitudinal Λ polarization, P_Λ, in $e^+e^- \to \Lambda + X$ at LEP I and LEP II energies as a function of z. The data of ALEPH and those of OPAL are taken from [10] and [16] respectively.
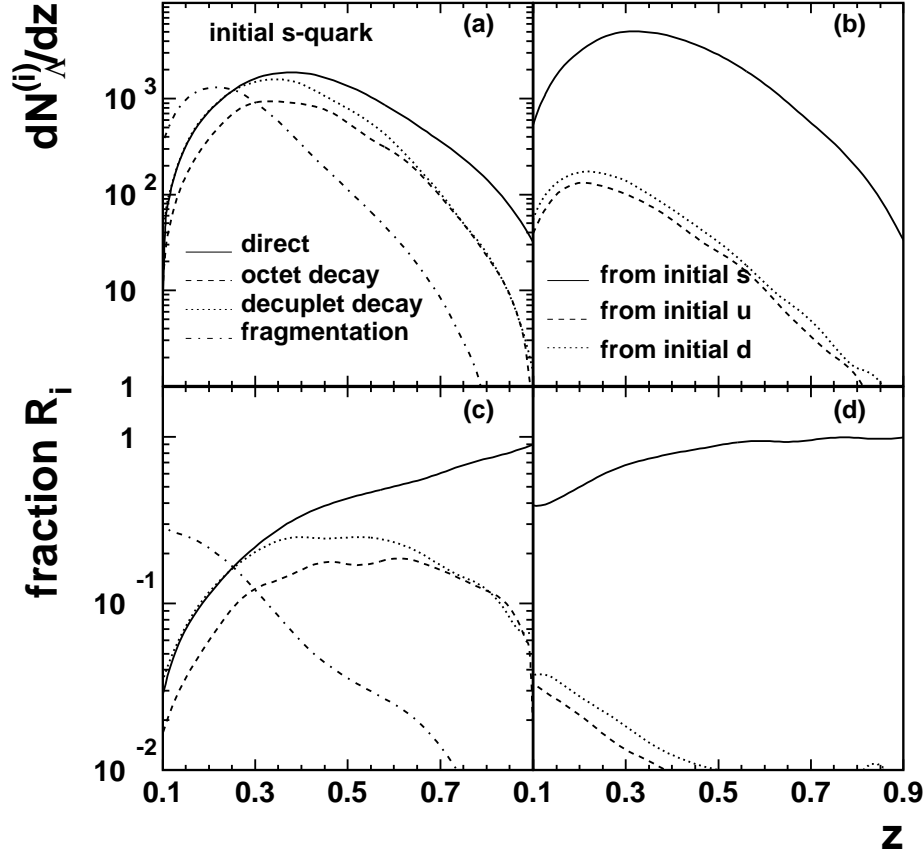
Fig. 6. Different contributions to Λ in the subsample of events where Λ is the leading particle in one direction and the leading in the opposite direction is K^+ at LEP I energy. In (a), we see the different contributions in the events with initial s-quarks. The means of the four curves are the same as those in Fig.4a. In (b), we see the contributions from the initial s, u or d events. In (c) and (d), we see the corresponding fractions of the contributions in (a) and (b) to all Λ in the subsample of events.
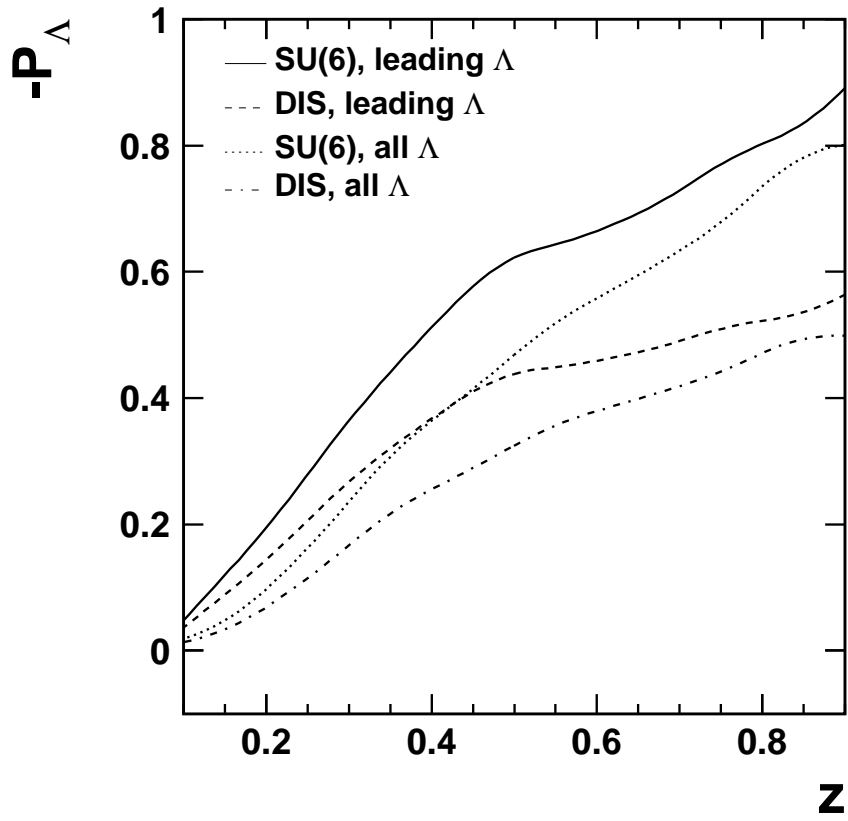
Fig. 7.   Comparison of P_Λ as a function of z in the subsample of events where Λ is the leading in one direction and K^+ is the leading in the opposite direction with that in the average events at LEP I energy.
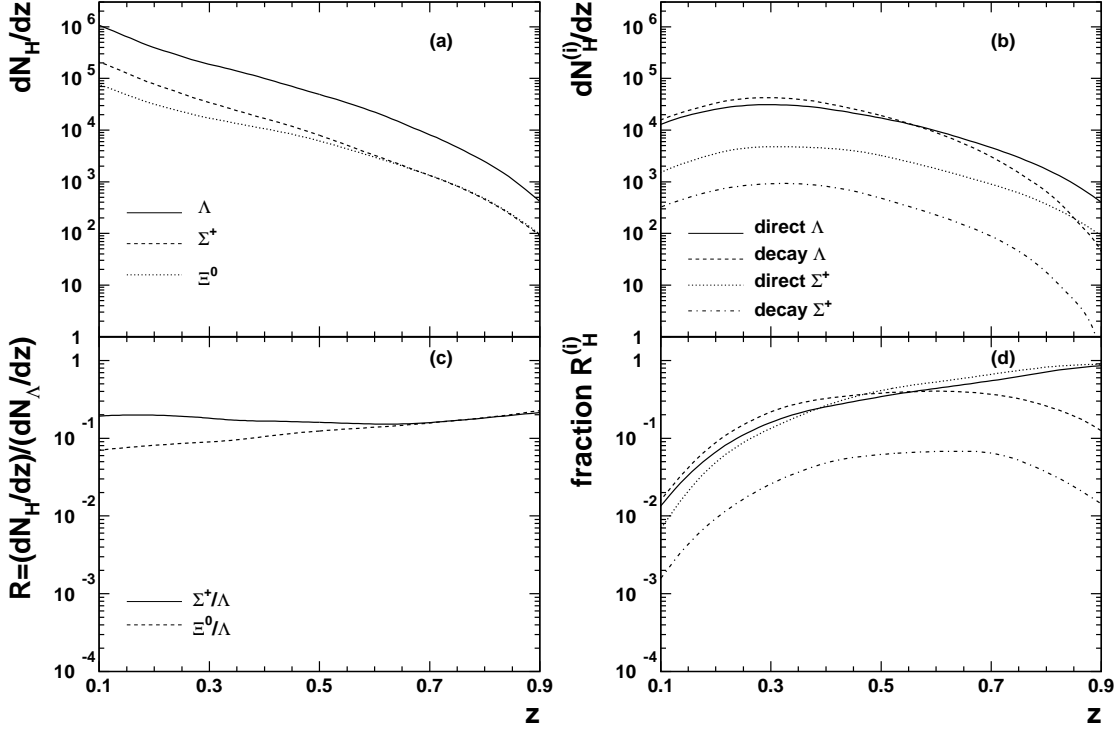
Fig. 8. Comparison of the different contributions to Λ, Σ^+ or Ξ^0 in e^+e^- annihilation at LEP I energy. In (a) and (c), we see a comparison of the production rates of Σ^+, Ξ^0 to that of Λ. In (b), we see a comparison of the two different classes of contributions to Λ and those to Σ^+. Here, "directly" represents the contribution from those which are directly produced and contain the initial quarks; "decay" denotes the contribution from polarized heavier hyperon decay. In (d), we see the ratios of contributions shown in (b) to all Λ or all Σ^+ respectively.
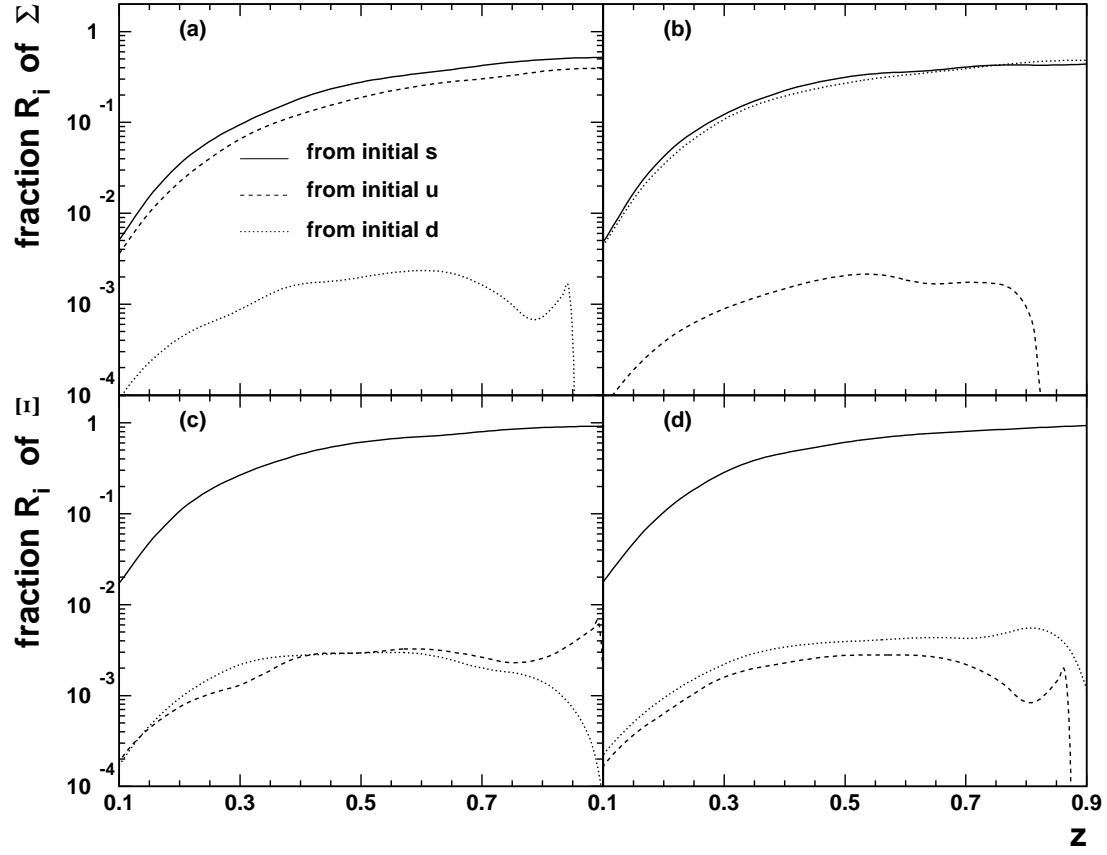
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Fig. 9. Contributions to Σ^+, Σ^-, Ξ^0 and Ξ^- from the different sources in e^+e^- annihilation at LEP I energy. Here, only those which contribute to hyperon polarization are included, i.e., the curves represent the corresponding sums of those which are directly produced and contain the initial q_i^0 with those from the decays of the polarized heavier hyperons.
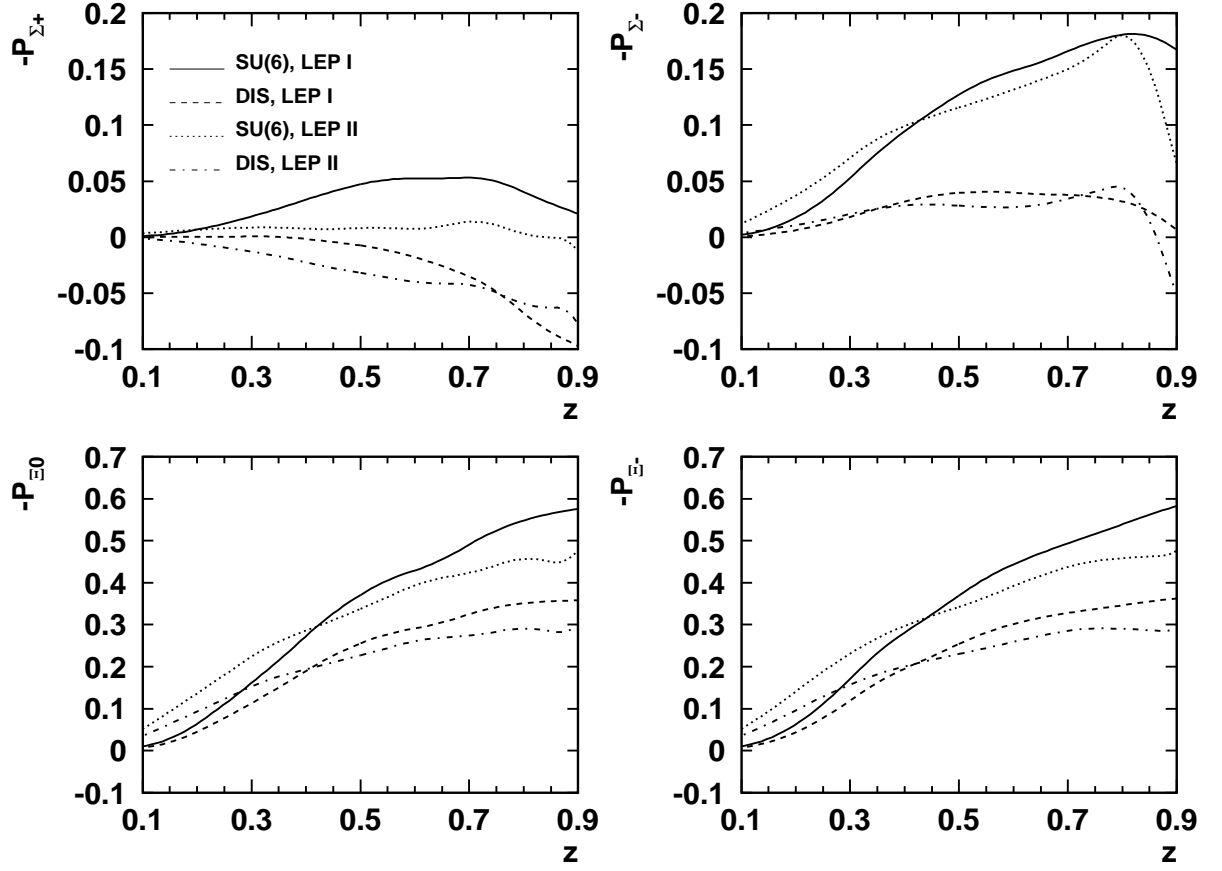
Fig. 10.   Calculated results of the longitudinal polarizations of Σ^+, Σ^-, Ξ^0 and Ξ^- in e^+e^- annihilation at LEP I and LEP II energies as functions of z from the two different pictures.